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EPM-NORTH CENTRAL, INC.'S  
COMMENTS ON THE MARCH 25, 1993  
BASELINE RISK ASSESSMENT FOR THE  
LENZ OIL SERVICE, INC. SITE  
LEMONT, ILLINOIS  
JANUARY 24, 1995

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COMMENTS ON THE MARCH 25, 1993  
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LENZ OIL SERVICE, INC. SITE  
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JANUARY 24, 1995

PREPARED FOR:  
LENZ OIL PARTICIPATING RESPONDENTS

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BASELINE RISK ASSESSMENT FOR THE  
LENZ OIL SERVICE, INC. SITE  
LEMONT, ILLINOIS  
JANUARY 24, 1995

This document presents comments on the March 25, 1993 "Baseline Risk Assessment for the Lenz Oil Service, Inc. Site, Lemont, Illinois, Revised Final Report" (the RA). Environmental Resources Management-North Central, Inc. (ERM-North Central) has reviewed the RA and prepared these comments on behalf of the Lenz Oil Participating Respondents, as a necessary part of preparing Revision 1 of the Feasibility Study (FS) for the Lenz Oil Site. The RA was prepared by PRC Environmental Management, Inc. (PRC) under contract to the U.S. Environmental Protection Agency (USEPA). The March 25, 1993 version is a revision of the August 24, 1992 RA, which had been modified to address ERM-North Central's comments of October 23, 1992.

## 1.0 INTRODUCTION

The comments on the modified document are divided into two categories:

- Comments that significantly affect the final results of the RA (Section 2.0), and

- Comments on the extent to which the results of the LNAPL investigation affect conclusions reported in the RA (Section 3.0).

While the Lenz Oil Participating Respondents do not believe that it is necessary for USEPA to revise the RA based upon these comments, the Respondents believe the comments must be considered by USEPA in connection with its evaluation of the upcoming Revision 1 to the FS and subsequent decision on the selection of a remedy.

## **2.0 INHALATION RISKS**

In general, these comments relate to the cancer risks calculated in the RA for exposure of current adjacent residents and future on-site and adjacent residents via inhalation of organics naturally volatilized from the soils. These cancer risks, which were calculated to be above the low threshold acceptable level of  $1 \times 10^{-6}$  in the RA, are, in fact, less than  $1 \times 10^{-6}$ , as shown in Attachment A and presented on the revised Tables 5.6 and 5.7. Because the inhalation risks are about four orders of magnitude lower than the values presented in the RA, the risks from exposure to soils should be about four orders of magnitude lower than presented in the RA.

More specifically, ERM-North Central disagrees with the modified method used to calculate the volatilization rates for organics emitted from the soils and the corresponding calculated inhalation risk because the resulting emission rates:

- Are excessively high when compared to the results obtained by using other methods described in documents published by the USEPA and the American Society for Testing and Materials (ASTM) (see Attachment A), and
- Deplete all the organics present at the site in less than seven days, which is highly unrealistic.

As indicated in Attachment A, at least three other methodologies could be used to determine the organics emission rates for the on-site soils. All of these methodologies result in emissions (and thus, risks from inhalation of volatilized organics) that are about four orders of magnitude less than those calculated in the RA. ERM-North Central suggests the use of the methodology included in the USEPA's Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals) (Interim, NTIS PB 93-963333, December 1991) because it was specifically developed for use at Superfund sites. Specific comments regarding this issue are set forth below, in the order in which the related information appears in the RA report.

1. **Pages 81 through 95, Section 4.3** - The parameters that are included in this section should be reevaluated after addressing the corrections indicated in these comments. For example, trichloroethene, tetrachloroethene, benzene, and trans-

1,3-dichloropropene would no longer produce cancer risks above  $1 \times 10^{-6}$  as a result of the exposure of future residents via inhalation of organics volatilized from the Area B soils. Because the corresponding cancer risks from exposure to these parameters via ingestion of and dermal contact with soil are less than  $1 \times 10^{-6}$ , the four aforementioned volatile organics would no longer be compounds of concern.

2. **Page 103, 5th through 7th Lines** - The air concentrations calculated by using the equations in Appendix F are unrealistic, i.e., they result in all of the volatile organics volatilizing from the soil in less than seven days, which is certainly not the case at the site. The RA should be modified by:
  - Recalculating the ambient air concentrations in Appendix E by using one of the three methodologies referenced in Attachment A to obtain more realistic results;
  - Modifying the associated tables in Appendix J by using the revised ambient air concentrations; and
  - Adjusting the conclusions presented in this section, as well as in Section 7.0 and the Executive Summary, to reflect the new results of the Appendix J calculations.
3. **Page 141, 2nd Paragraph** - As indicated in Comment 4.a and discussed in Attachment A of this comment document, all of the inhalation risks should be recalculated.



#### 4. Appendix E

- a. **Pages E-1 through E-3** - The new equations being used to calculate the air emissions resulting from the volatilization of organics from the soils result in the depletion of all of the volatile organics from the site soils in less than seven days. Attachment A of this comment document summarizes the calculations performed to arrive at this conclusion, and lists three other methodologies that could be used to calculate the air emissions that would result in more realistic air concentrations and inhalation risks. To be more realistic, the methodology in the USEPA's Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals (NTIS PB 92-963333, December 1991) should be used for the calculation of the ambient air concentrations resulting from the volatilization of organics from soils and all of the inhalation risk calculations should be repeated.
- b. **Page E-2, Definitions of R and T** - The values given for these two variables are incorrect. The value of the gas constant should be  $8.2 \times 10^{-5}$  atm-m<sup>3</sup>/mol-°K and the temperature 293 °K. The value shown for the gas constant on this page is actually the value of the product of R x T.
- c. **Page E-4, Table E-1** - Some of the soil concentrations shown on this table do not coincide with the RME values developed from the data presented on Page C-19 of Appendix C as indicated on Page 28. The methodology includes using either: (1) the maximum detected concentration if the "95-Percent UCL" is higher than the maximum detected concentration, or (2)

the "95-Percent UCL" otherwise. Specifically, the soil concentrations for the following parameters are different from those developed by using Appendix C: methylene chloride; 1,1,1-trichloroethane; 2-methylnaphthalene; phenanthrene; anthracene; di-n-butylphthalate; fluoranthene; pyrene; benzo(a)anthracene; chrysene; benzo(b)fluoranthene; benzo(k)fluoranthene; benzo(a)pyrene; indeno(1,2,3-cd)perylene; and benzo(g,h,i)pyrene.

- d. **Page E-5, Table E-2** - The soil concentrations shown on this table for methylene chloride; trans-1,3-dichloropropene; toluene; di-n-butylphthalate; butyl benzyl phthalate; bis(2-ethylhexyl)phthalate; benzo(b)fluoranthene; benzo(k)fluoranthene; indeno(1,2,3-cd)pyrene; benzo(g,h,i)perylene; and Aroclors 1242 and 1254 do not coincide with the RMEs developed by using Appendix C, Page C-22.
- 5. **Appendix J, Tables J-7, J-10, and J-14** - These tables should be modified after the air concentrations are recalculated. Also, according to Table 4-4, the inhalation slope factor for benzene in Table J-10 should be  $2.9 \times 10^{-2}$  instead of  $2.4 \times 10^{-2}$ .

### 3.0 EFFECT OF THE NEWLY COLLECTED SOIL DATA ON THE BASELINE RISK ASSESSMENT RESULTS

Between August 2 and 5, 1994 ERM-North Central collected four additional soil samples during the installation of piezometers P-01, P-06, P-08, and P-13 to delineate the extent of the light nonaqueous phase liquid presented at the Lenz Oil Site. These comments present an evaluation of the effect of the newly collected soil data on the Baseline Risk Assessment [RA] for the Lenz Oil Services, Inc. Site, Lemont, Illinois, prepared by PRC Environmental Management, Inc. dated March 25, 1993.

The laboratory analytical results for the additional soil samples, which are summarized in Table 3-1, were compared to the soil data obtained during the RI. Based on this comparative analysis, the following three parameters were not detected during the RI, but were found during the LNAPL investigation at the concentrations shown:

- Chlorobenzene, 6 J ug/kg;
- 3 Nitroaniline, 97 J ug/kg; and
- n-Nitrosodiphenylamine, 1,900 J ug/kg.

On December 28, 1994, ERM-North Central performed a search of the U.S. Environmental Protection Agency's (USEPA) Integrated Risk Information System on line database and the 1994 Health Assessment Effects Tables to determine the available toxicity factors for these parameters. The toxicity factors, detected soil concentrations, and RA equations (shown on Pages 47, 50, and 96 of the RA) were then used to calculate the risks resulting from the ingestion and dermal contact with these parameters by future on-site residents.

As shown in Table 3-2, the calculated excess carcinogenic and noncarcinogenic risks resulting from exposure to these parameters are at least two and four orders of magnitude lower than the total calculated excess carcinogenic and noncarcinogenic risks presented in the revised Tables 5-6 and 5-7 for the site soils. Therefore, the risks resulting from compounds detected during the LNAPL investigation but not detected during the RI, do not change the total risks calculated from the site soils, as shown in the revised Tables 5-6 and 5-7.

## **TABLES**

\* ABLE 3-1

Location	P01	P06	P08	P13	P24
Sample Designation	LOSP01E (2)	LOSP06D	LOSP08D	LOSP13I	LOSP24E (3)
Sample Depth (feet BGS)	8-10'	6-8'	8-8'	8-10'	8-10'
Collection Date	08/02/94	08/02/94	08/05/94	08/03/94	10/14/94
<b>Volatile Organics (ug/kg)</b>					
Acetone	15 U	280	31	12 U	32 U
1,1-Dichloroethene	17 U	15 U	11 U	1	24
1,1,1,2-Tetrachloroethene	17 U	15 U	11 U	17	140
1,1,2-Trichloroethane	17 U	15 U	11 U	11 U	7
2-Chloropropane	5	86	11 U	11 U	11 U
1,1,2-Dichloroethane	17 U	15 U	11 U	3	11 U
Benzene	33	18	11 U	14	93 U
1,2-Dichloroethane	17 U	15 U	11 U	1	11 U
1-Hexene	3 U	22	2 U	11	71 U
p-Tolylbenzene	6 U	15 U	11 U	11 U	11 U
Ethyl Benzene	550	85	11 U	1	163
1,4-Di-Xylenes	720	570	11 U	7 U	74
<b>Semivolatile Organics (ug/kg)</b>					
1,2-Dichlorobenzene	800 U	2,400 U	3700 U	27 U	1,800 U
Naphthalene	1,600 U	2,400 U	3700 U	11 U	1,800 U
2-Methylnaphthalene	39,000	790 U	3700 U	180 U	1,600 U
n-Nitroaniline	5,700 U	2,400 U	3700 U	40 U	87 U
m-Nitrosodiphenylamine	5,700 U	2,400 U	1900 U	40 U	1,800 U
Fluorene	5,700 U	2,400 U	3700 U	4 U	200 U
Phenanthrene	5,300 U	2,400 U	3700 U	370 U	480 U
3-n-Butylphthalate	5,700 U	2,400 U	3700 U	40 U	240 U
bis(2-Ethylhexyl)phthalate	5,700 U	2,400 U	3700 U	40 U	320 U
<b>Pesticides/PCBs (ug/kg)</b>					
Aroclor-1242	290 U	9,800	37 U	37 U	49 U
Aroclor-1248	610	970 U	90 U	37 U	37 U
Aroclor-1254	600	6,900	59 U	37 U	37 U
Aroclor-1260	470	970 U	44 U	37 U	37 U
<b>Inorganics (mg/kg)</b>					
Aluminum	20,200 U	16,600 U	1,030 U	2,770 U	1,780
Arsenic	16.4 U	12.1 U	8.0 U	2.8 U	2.5
Barium	145	106	20 U	20 U	20 U
Beryllium	1.6 U	1.6 U	0.4 U	1.4 U	0.4 U
Cadmium	8,160	7,780	157,000	154,000	166,000
Chromium	30.2	23.6	4.3 U	7.4	5.9 U
Cobalt	14.8	8.7	2.1 U	3.9	2.0 U
Copper	48.3	17.3	3.2	8.8	4.9
Iron	29,700	49,500	14,100	6,280	50,000
Lead	32.4 U	79.3 U	2.1 U	3.1 U	4
Magnesium	5,520	5,190	95,300	90,600	86,300
Manganese	322 U	352 U	342 U	266 U	197
Nickel	39.4 U	19.5 U	4.0 U	6.5 U	4.0 U
Potassium	3,060	2,040	479	470	732
Selenium	4.5	1.0	0.4 U	0.4 U	0.2 U
Silver	1.0 U	2.0	1.0 U	1.0 U	1.0 U
Sodium	722	749	400 U	400 U	400 U
Vanadium	41.7	43.0	2.0 U	5.6	4.3
Zinc	117	118	9.7 U	12.2 U	118

Notes:

- (1) Only the parameters detected in at least one sample are shown.  
(2) Because SVOCs were reanalyzed, indicated result is either (1) the greater of two positive results, (2) the greater of two estimated results, or (3) the nonqualified, positive result if one of the values was estimated. The detection limits shown are the lower of the two analyses.  
(3) A dilution of the investigative sample for LOSP24E was analyzed for volatile organics. The reported result is either (1) the greater of two positive results, (2) the greater of two estimated results, or (3) the nonqualified, positive result if one of the values was estimated. The detection limits shown are the lower of the two analyses.

Key:

BGS : Beneath ground surface  
 U : Not detected at the detection limit shown  
 E : Estimated.  
 PCBs : Polychlorinated biphenyls  
 SVOCs : Semivolatile organic compounds

TABLE 3-2  
CARCINOGENIC AND NONCARCINOGENIC RISKS FOR  
POTENTIAL ADDITIONAL PARAMETERS OF CONCERN  
LENZ OIL SITE  
LEMONT, ILLINOIS

Parameter	Chlorobenzene	3-Nitroaniline	n-Nitrosodiphenylamine
Toxicity Factors			
Oral Slope Factor, 1/(mg, kg, d)	NA	NA	0.049
Oral Reference Dose, mg/kg/d	0.02	NA	NA
Concentration, mg/kg	0.006 [	0.097 [	1.9 [
Soil Ingestion Rate, mg/d			
Child	200	200	200
Adult	100	100	100
Absorption factor	0.25	0.1	0.1
Soil-to-Skin Adherence Factor, mg/cm <sup>2</sup>	1	1	1
Surface Area Available for Contact, cm <sup>2</sup>			
Child	1,048	1,048	1,048
Adult	2,666	2,666	2,666
Body Weight, kg			
Child	15	15	15
Adult	70	70	70
Exposure Frequency, d/yr	350	350	350
Exposure Duration, yr			
Child	6	6	6
Adult	24	24	24
Averaging Time, d			
Carcinogenic	25,550	25,550	25,550
Noncarcinogenic			
Child	2,190	2,190	2,190
Adult	8,760	8,760	8,760
Conversion Factor, kg/mg	1E-06	1E-06	1E-06
Risk from Soil Ingestion			
Carcinogenic	NA	NA	1E-08
Noncarcinogenic			
Child	4E-06	NA	NA
Adult	4E-07	NA	NA
Risk from Dermal Contact with Soil			
Carcinogenic	NA	NA	2E-08
Noncarcinogenic			
Child	5E-06	NA	NA
Adult	3E-06	NA	NA

TABLE 5-6  
(REVISED - JANUARY 1995)

SUMMARY OF EXCESS CANCER RISKS  
LENZ OIL SITE  
LEMONT, ILLINOIS

Exposure Pathway	Current Recreational Assumed Conditions - Des Plaines River				Current Trespasser		Current Adjacent Resident		Future Residential - On Site		Future Resident Adjacent to Site		Future Short-Term Worker	
	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)
Surface Water														
Dermal Contact	2E-09	Table J-2	8E-09	Table J-3	-	-	-	-	-	-	-	-	-	-
Ingestion	6E-08	Table J-1	6E-08	Table J-1	-	-	-	-	-	-	-	-	-	-
Total Excess Cancer Risk - Surface Water	6E-08	-	7E-08	-	-	-	-	-	-	-	-	-	-	-
Sediment														
Dermal Contact	6E-08	Table J-4	--	--	--	--	--	--	--	--	--	--	--	--
Total Excess Cancer Risk - Sediment	6E-08	-	-	-	-	--	--	--	--	--	--	--	--	--
Soil														
Dermal Contact (Area B)	--	--	-	--	2E-06	Table J-6	2E-06	Table J-6	4E-05	Table J-9	2E-06	Table J-6	4E-07	Table J-8
Ingestion (Area B)	--	--	--	--	4E-07	Table J-5	4E-07	Table J-5	3E-05	Table J-8	4E-07	Table J-5	4E-07	Table J-27
Inhalation, Particulates (Area B)	--	--	--	--	-	-	3E-08	Table J-11	3E-08	Table J-11	2E-08	Table J-11	2E-08	Table J-11
Inhalation, VOC Emissions (Area B)	--	--	--	--	< 1E-08	(2)	< 1E-08	(2)	< 1E-08	(2)	< 1E-08	(2)	< 1E-08	(2)
Total Excess Cancer Risk - Soil	--	--	-	--	2E-06	-	2E-06	--	7E-05	-	2E-06	-	4E-08	-
Ground Water														
Ingestion	-	-	--	--	--	--	Table J-21	2E-02	Table J-13	3E-04	Table J-13	3E-04	Table J-13	3E-04
Dermal Contact	-	-	--	--	--	-	Table J-22	3E-02	Table J-16	8E-06	Table J-16	8E-06	Table J-16	8E-06
Inhalation, Shower VOC Emissions	-	-	--	--	-	-	Table J-23	5E-07	Table J-17	6E-07	Table J-17	6E-07	Table J-17	6E-07
Total Excess Cancer Risk - Ground Water	-	-	--	--	-	-	-	7E-02	-	3E-04	-	3E-04	-	3E-04
<b>TOTAL EXCESS CANCER RISK</b>	1E-07	--	7E-08	-	2E-06	--	2E-06	-	5E-02	-	3E-04	-	4E-08	-

Notes:

- (1) From the BASELINE RISK ASSESSMENT FOR THE LENZ OIL SERVICE, INC. - SHELL LEMONT, ILLINOIS, REVISED FINAL REPORT prepared by PRO-TECH, Inc., dated March 25, 1993.
- (2) Estimated to be at least less than 1E-08, based on the calculations presented in Attachment 1 to the Comments on the Baseline Risk Assessment, Free-Flow Environmental Services, Inc., dated January 18, 1995. Remediation Goals memorandum, also dated January 18, 1995.

Key:

-- Not applicable



TABLE 5-7  
(REVISED - JANUARY 1995)

SUMMARY OF HAZARD INDICES  
LENZ OIL SITE  
LEMMONT, ILLINOIS

Exposure Pathway	Current Recreational						Current Adjacent Resident		Future Residential - On Site		Future Resident Adjacent to Site		Future Short-Term Worker	
	Drainage Ditch		Assumed Conditions - Des Plaines River		Current Trespasser									
	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)	Value	Source (1)
Surface Water														
Dermal Contact	2E+05	Table J-2	6E+05	Table J-3	--	--	--	--	--	--	--	--	--	--
Ingestion	6E+04	Table J-1	6E+04	Table J-1	--	--	--	--	--	--	--	--	--	--
Total Hazard Indices - Surface Water	6E+04		6E+04	--	--	--	--	--	--	--	--	--	--	--
Sediment														
Dermal Contact	2E+04	Table J-4	--	--	--	--	--	--	--	--	--	--	--	--
Total Hazard Indices - Sediment	2E+04	--	--	--	--	--	--	--	--	--	--	--	--	--
Soil														
Dermal Contact (Area B)	--	--	--	--	5E+04	Table J-6	5E+04	Table J-6	1E+02	Table J-9	5E+04	Table J-6	4E+03	Table J-28
Ingestion (Area B)	--	--	--	--	1E+03	Table J-5	1E+03	Table J-5	2E+01	Table J-8	1E+03	Table J-6	2E+00	Table J-27
Inhalation, Particulates (Area B)	--	--	--	--	--	--	9E+09	Table J-11	9E+09	Table J-11	9E+09	Table J-11	--	--
Inhalation, VOC Emissions (Area B)	--	--	--	--	<1E+08	(2)	<1E+08	(2)	1E+08	(2)	<1E+08	(2)	<1E+08	(2)
Total Hazard Indices - Soil	--	--	--	--	2E+03	--	2E+03	--	2E+01	--	2E+02	--	2E+02	--
Ground Water														
Ingestion	--	--	--	--	--	--	--	Table J-21	1E+01	Table J-15	3E+01	Table J-17	--	--
Dermal Contact	--	--	--	--	--	--	--	Table J-22	2E+01	Table J-16	7E+03	Table J-22	--	--
Inhalation, Shower VOC Emissions	--	--	--	--	--	--	--	Table J-23	4E+03	Table J-17	8E+04	Table J-23	--	--
Total Hazard Indices - Ground Water	--	--	--	--	--	--	--	--	1E+01	--	4E+01	--	2E+01	--
TOTAL HAZARD INDICES	9E+04	--	6E+04	--	2E+03	--	2E+03	--	1E+01	--	3E+01	--	2E+01	--

**Note:**

- (1) From the BASELINE RISK ASSESSMENT FOR THE LENZ OIL SERVICE, INC. SITE, LEMMONT, ILLINOIS, REVISED FINAL REPORT, prepared by DEC Environmental Management, Inc. and dated March 25, 1993.
- (2) Estimated to be at least less than 1E+08, based on the calculations presented in Attachment I to the Comments on the Baseline Risk Assessment, dated January 18, 1995, and the Proposed Remediation Goals memorandum, also dated January 18, 1995.

**Key:**

Not applicable

## ATTACHMENT A

ATTACHMENT A

BASELINE RISK ASSESSMENT COMMENTS  
EVALUATION OF THE METHODOLOGY USED  
TO CALCULATE AMBIENT AIR CONCENTRATIONS  
FROM THE VOLATILIZATION OF ORGANICS  
LENZ OIL SITE  
LEMONT, ILLINOIS

1.0 INTRODUCTION

This attachment to the Comments on the March 25, 1993 "Baseline Risk Assessment for the Lenz Oil, Inc., Site, Lemont, Illinois" (the "RA") presents an evaluation of the methodology used to calculate the estimated ambient air concentrations produced by the volatilization of organics at the site. This evaluation was prompted by the high calculated cancer risks of more than  $1 \times 10^{-5}$  for volatile organics detected at concentrations lower than 0.5 mg/kg. The associated level of volatilization resulted in the dissipation of all of the volatile organic compounds (VOCs) from the site in less than seven days, which is highly unrealistic.

After reviewing the available data, Environmental Resources Management-North Central, Inc. (ERM-North Central) used other methodologies published by the U.S. Environmental Protection Agency (USEPA) and the American Society for Testing and Materials (ASTM) to calculate the ambient air concentrations for the Lenz Oil site as a comparison check. The results of these calculations show that the concentrations presented in the RA are at least three orders of magnitude higher than the concentrations calculated by using other methodologies. Therefore, a more realistic procedure should be used to estimate the ambient air concentrations resulting from the volatilization of organics. The

following sections include an evaluation of the methodology described in Appendix E of the RA and a brief summary of possible alternative protocols.

## 2.0 BASELINE RISK ASSESSMENT METHODOLOGY

As shown on Pages E-1 through E-3 of Appendix E of the RA, ambient air concentrations were calculated by using the Farmer model described in the USEPA's Superfund Exposure Assessment Manual (EPA/540/1-88/001, April 1988), and determining the soil gas concentrations by using the USEPA's Air/Superfund National Technical Guidance Study Series: Assessing Potential Indoor Air Impacts for Superfund Sites (EPA-451/R-92-00, 1992). The results of the calculations are shown on Tables E-1 and E-2 of Appendix E of the RA.

The time required for the compounds in the soil to be depleted through volatilization can be calculated by using the initial mass of the compound in the soil and the Appendix E emission rate per square meter, as follows:

$$t = \frac{M}{E'}$$

Where:

- t = Time for depletion of the organics, d
- M = Mass of the organic chemical in the soil, g
  - =  $C_s \times \rho \times V \times 1 \times 10^{-6} \text{ g}/\mu\text{g}$
- $C_s$  = Soil concentration,  $\mu\text{g}/\text{kg}$
- $\rho$  = Soil density =  $1,700 \text{ kg}/\text{m}^3$

- $V$  = Contaminated soil volume, m<sup>3</sup>  
 =  $A \times d$   
 $A$  = Contaminated soil area = 5,300 m<sup>2</sup> and 17,200 m<sup>2</sup> for Areas A and B soils, respectively (see Page F-4 of Appendix F)  
 $d$  = Contaminated soil depth = 3 m for both Areas A and B  
 $E'$  = Emission rate, g/d  
 =  $E \times A \times 86,400 \text{ s/d}$   
 $E$  = Emission rate per square meter, g/s/m<sup>2</sup>

For example, the depletion time interval for benzene (i.e., from the Area A soils), would be calculated by using a value of  $C_s$  of 14.9 µg/kg and a value of  $E$  of  $3.12 \times 10^{-7}$  g/s/m<sup>2</sup> as listed on Table E-1 of Appendix A.

The resulting time is:

$$\begin{aligned}
 t &= \frac{(14.9 \text{ } \mu\text{g/kg}) (1,700 \text{ kg/m}^3) (5,300 \text{ m}^2) (3\text{m}) \times (1 \times 10^{-6} \text{ g/}\mu\text{g})}{(3.12 \times 10^{-7} \text{ g/s/m}^2) (5,300 \text{ m}^2) (86,400 \text{ s/d})} \\
 &= 2.82 \text{ days}
 \end{aligned}$$

The depletion times for the other parameters of concern in the Areas A and B soils (i.e., parameters shown with a calculated cancer risk higher than  $1 \times 10^{-6}$  on Tables J-10 and J-14 of Appendix J of the RA) are provided on Table A-1 of this Attachment A. As indicated in Table A-1, all of the calculated times for the dissipation of all of the VOC mass in the soils are less than seven days.

### 3.0 OTHER GUIDELINES

Methodologies to calculate the ambient air concentrations resulting from the volatilization of organics were obtained from the following sources:

- Equation 17 in the USEPA's Air/Superfund National Technical Guidance Study Series, Volume II - Estimation of Baseline Air Emissions at Superfund Sites, EPA-450/1-89-a, August 1990.
- Equation 8 in the USEPA's Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals), NTIS PB92-963333, December 1991. This equation provides a volatilization factor (VF) in  $\text{m}^3/\text{kg}$ . The ambient air concentration can be calculated by dividing the soil concentration by the calculated value of VF.
- Equation for calculating the value of  $\text{VF}_{\text{samb}}$  in  $\text{kg}/\text{m}^3$  (i.e., the factor to estimate volatilization of organics from subsurface soils to the ambient air) in the ASTM's Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ES 38-94, July 1994. The ambient air concentration can be calculated by multiplying the soil concentration times the calculated value of  $\text{VF}_{\text{samb}}$ .

Copies of the specific pages of these documents that present the aforementioned equations are attached as Exhibit A. Table A-2 presents a comparison of the values on: (1) the emission rate per square meter calculated by using the methods in the RA and the USEPA 1990 document, and (2) the air concentrations calculated by using the method in the RA and the USEPA 1991 and ASTM documents. In addition, the chemical-specific data required for these calculations are shown on Table A-3. As indicated in Table A-2, the values calculated in the RA are approximately four to six orders of magnitude higher than the values calculated by using any other guidance.

#### **4.0 CONCLUSIONS**

Based on the values presented in Table A-2, the risk from the inhalation of volatilized organics would be about four orders of magnitude lower (i.e., given the linear relationship between ambient air concentration and risk) than those presented on Tables J-10 and J-14 of Appendix J of the RA and are, therefore, not of concern for the Lenz Oil site.

TABLE A-1

TIME FOR DEPLETION OF ORGANICS IN SOILS AS A RESULT OF VOLATILIZATION  
 BASED ON THE BASELINE RISK ASSESSMENT CALCULATIONS  
 LENZ OIL SITE  
 LEMONT, ILLINOIS

Area	Parameter	Soil Concentration (ug/kg)	Soil Density (kg/m <sup>3</sup> )	Contaminated Area (m <sup>2</sup> )	Contaminated Depth (m)	Contaminated Soil Volume (m <sup>3</sup> )	Mass of Contaminant in Soil (g)	Normalized Emission Rate (g/s/m <sup>2</sup> )	Emission Rate (g/d)	Time for disappearance (d)
A	Trichloroethene	74.9	1,700	5,300	3	15,900	2.02E+03	1.48E-06	6.78E+02	2.99
	Tetrachloroethene	100	1,700	5,300	3	15,900	2.70E+03	1.78E-06	8.14E+02	3.32
	Benzene	14.9	1,700	5,300	3	15,900	4.03E+02	3.12E-07	1.43E+02	2.82
B	Trichloroethene	69.7	1,700	17,200	3	51,600	6.11E+03	1.38E-06	2.05E+03	2.99
	Tetrachloroethene	217	1,700	17,200	3	51,600	1.90E+04	3.86E-06	5.73E+03	3.32
	Benzene	15.9	1,700	17,200	3	51,600	1.39E+03	3.33E-07	4.95E+02	2.82
	trans-1,3-Dichloropropene	2.07	1,700	17,200	3	51,600	1.82E+02	1.77E-08	2.62E+01	6.9



**TABLE A-2**  
**COMPARISON OF EMISSION RATES AND AMBIENT AIR CONCENTRATIONS**  
**CALCULATED BY USING DIFFERENT METHODOLOGIES**  
**LENZ OIL SITE**  
**LEMONT, ILLINOIS**

Area	Parameter	Normalized Emission Rate (g/s/m <sup>2</sup> )		Ambient Air Concentrations (g/m <sup>3</sup> )		
		Baseline Risk Assessment	USEPA, 1990	Baseline Risk Assessment	USEPA, 1991	ASTM ES 38-94
A	Trichloroethene	1.48E-06	2.05E-10	2.25E-01	6.80E-08	7.46E-06
	Tetrachloroethene	1.78E-06	9.71E-11	2.96E-01	8.57E-08	1.10E-05
	Benzene	3.12E-07	4.53E-11	4.18E-02	1.37E-08	1.39E-06
B	Trichloroethene	1.38E-06	1.90E-10	2.10E-01	1.15E-07	6.95E-06
	Tetrachloroethene	3.86E-06	2.11E-10	6.43E-01	3.39E-07	2.40E-05
	Benzene	3.33E-07	4.83E-11	4.46E-02	2.66E-08	1.48E-06
	trans-1,3-Dichloropropene	1.77E-08	2.38E-12	2.34E-03	1.88E-09	6.73E-08

**Key:**

USEPA, 1990 = AIR/SUPERFUND NATIONAL TECHNICAL GUIDANCE STUDY SERIES VOLUME II - ESTIMATION OF BASELINE AIR EMISSIONS AT SUPERFUND SITES, U.S. Environmental Protection Agency, EPA-450/1-89-002a, August 1990.

USEPA, 1991 = RISK ASSESSMENT GUIDANCE FOR SUPERFUND: VOLUME I - HUMAN HEALTH EVALUATION MANUAL (PART B, DEVELOPMENT OF RISK-BASED PRELIMINARY REMEDIATION GOALS) Interim, U.S. Environmental Protection Agency, NTIS PB 92-963333, December 1991.

ASTM ES 38-94 = EMERGENCY STANDARD GUIDE FOR RISK-BASED CORRECTIVE ACTION APPLIED AT PETROLEUM RELEASE SITES, ES 38-94, American Society for Testing and Materials.

TABLE A-3

**ADDITIONAL PHYSICO-CHEMICAL DATA REQUIRED TO CALCULATE THE  
VOLATILIZATION OF CONTAMINANTS FROM SUBSURFACE SOILS  
LENZ OIL SITE  
LEMONT, ILLINOIS**

Area	Parameter	Henry's Law Constant (1) (atm-m <sup>3</sup> /mol)	Vapor Pressure (atm)	Molecular Weight (g/mole)	Diffusivity in Air (1) (cm <sup>2</sup> /s)	Diffusivity in Water (cm <sup>2</sup> /s)	Effective Diffusion Coefficient in Soil (cm <sup>2</sup> /s)	Organic Carbon Water Partition Coefficient (1) (ml/g)	Effective Diffusivity in Air (cm <sup>2</sup> /s)	Soil/Air Partition Coefficient (g/cm <sup>3</sup> )	Alpha (cm <sup>2</sup> /s)
A	Trichloroethene	0.0091	0.0762	131	8.12E-02	9.65E-06	2.01E-02	126	5.74E-02	2.96	0.0278
	Tetrachloroethene	0.0259	0.0234	166	7.41E-02	8.69E-06	1.83E-02	364	5.24E-02	2.92	0.0252
	Benzene	0.00559	0.1253	78	9.23E-02	1.10E-05	2.29E-02	83	6.53E-02	2.76	0.0305
B	Trichloroethene	0.0091	0.0762	131	8.12E-02	9.65E-06	2.01E-02	126	5.74E-02	2.96	0.0278
	Tetrachloroethene	0.0259	0.0234	166	7.41E-02	8.69E-06	1.83E-02	364	5.24E-02	2.92	0.0252
	Benzene	0.00559	0.1253	78	9.23E-02	1.10E-05	2.29E-02	83	6.53E-02	2.76	0.0305
	trans-1,3-Dichloropropene	0.0013	0.0329	111	9.35E-02	9.59E-06	2.33E-02	48	6.61E-02	1.11	0.0172

**Other Parameters:**

RT (atm-m <sup>3</sup> /mole)	0.024
Organic carbon content of soil (g/g)	0.001
Total soil porosity (cm <sup>3</sup> /cm <sup>3</sup> )	0.35
Depth of soil cover (cm)	30.5
Length of contaminated area (m)	
Area A	91
Area B	162
Wind speed (m/s)	4.6
Dispersion height (m)	2
Exposure interval (s)	7.9E+08
Volumetric air content of soil (cm <sup>3</sup> /cm <sup>3</sup> )	0.23
Volumetric water content of soil (cm <sup>3</sup> /cm <sup>3</sup> )	0.12

**ATTACHMENT A**  
**EXHIBIT A**

United States  
Environmental Protection  
Agency

Office of Air Quality  
Planning and Standards  
Research Triangle Park, NC 27711

*Current*

EPA-450/1-89-002a  
August 1990

AIR/SUPERFUND



# AIR / SUPERFUND NATIONAL TECHNICAL GUIDANCE STUDY SERIES

## VOLUME II - ESTIMATION OF BASELINE AIR EMISSIONS AT SUPERFUND SITES

\* This document revises earlier edition, EPA-450/1-89-002.

AIR/SUPERFUND NATIONAL  
TECHNICAL GUIDANCE STUDY  
SERIES

waste placed in hazardous and industrial waste landfills minimize gas production due to biodegradation.

#### Limitations--

The Shen Model does not account for the landfill gas losses in leachate systems, run off, or soils. But here again, due to the inert properties of the volatile constituents, this accountability is considered by Dr. Shen to be minute. The Shen Model also assumes that the soil is completely dry with no internal gas generation. However, the Shen Model can be modified to account for biogas generation with a multiplicative factor of 6. This assumption would tend to overestimate emissions by not accounting for actual wet soil conditions below the soil cover layer. As with the Farmer Model, the Shen Model does not account for emissions due to meteorological fluctuations (e.g., barometric pressure pumping).

Another limitation of the Shen Model is the incorporation of Raoult's Law to relate the waste composition to emission rate. Raoult's Law is applicable only to waste saturated with constituent *i* and ideal solutions. Application of the Shen Model to wastes containing dilute concentrations of the constituent *i* is likely to result in an overestimate of emission rate.

#### SEAMS Model--

The model recommended in the U.S. Environmental Protection Agency's SEAMS manual is a slightly modified version of the Shen Model (41). This modified model was proposed by Farino et.al. (49) who found that a more accurate approach would be to multiply by the mole fraction of the volatile component in the buried mixture.

$$E_i = D_i C_i A (P_t^{4/3}) \frac{M_i}{L} \quad (\text{Eq. 18})$$

where:  $E_i$  = emission rate of the component *i* (g/sec);  
 $D_i$  = diffusion coefficient of component in air (cm<sup>2</sup>/sec);  
 $C_i$  = saturated vapor concentration of component *i* (g/cm<sup>3</sup>);  
 $A$  = exposed area (cm<sup>2</sup>);  
 $P_t$  = total soil porosity (dimensionless);

- L = effective depth of soil cover (cm); and  
 $M_i$  = mole fraction of component i in the waste (gmole/gmole).

The SEAMS manual provides guidance on methods for estimating or calculate values for the model input parameters (41).

#### Applicability--

The SEAMS model applies to the same situations described for the Shen model.

#### Limitations--

The SEAMS model and Shen model have similar limitations; however, the SEAMS model relates the waste composition to the emission rate more accurately.

#### Thibodeaux a Model--

The Thibodeaux a Model (45,49) was developed by Thibodeaux to estimate the emissions of volatile constituents due to interphase vapor transport from landfills with no internal gas generation. The model is derived from Fick's Law of steady state diffusion. Molecular diffusion is the controlling and only transport mechanism addressed by the Thibodeaux a Model for the movement of volatile constituents toward the soil/air interface and then to the overlying air. To describe this mechanism, the two-resistance theory is used to describe the two-film resistance in which the movement of chemical constituents is limited by their ability to diffuse through the soil and after migration from the surface, through the air.

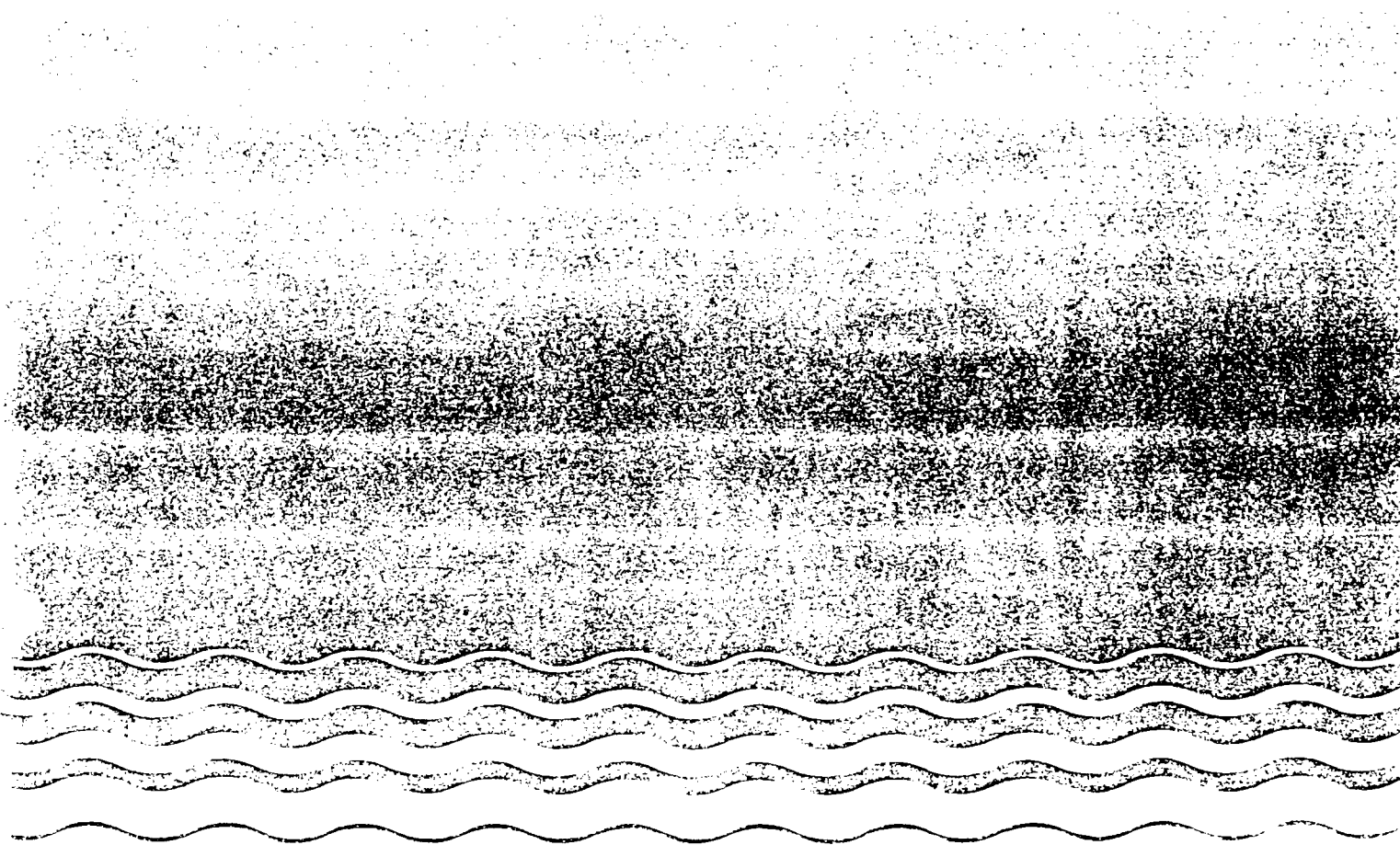
The model assumes that a pure component i exerts its pure component vapor pressure under the earth, subject to normal geophysical and meteorological factors. Thibodeaux defines an overall mass transfer coefficient to describe vapor movement which is hindered by both the resistance due to soil characteristics and diffusion resistances at the air interface.

$$E_i = {}^1K_i (C_i - C_{i1}) A \quad (\text{Eq. 19})$$

$$E_i = E_{\text{soil}} + E_{\text{air/soil}} \quad (\text{Eq. 20})$$

SEPA

# Superfund Exposure Assessment Manual



SECTION 101 OF THE CLEAN WATER ACT (CWA) AND SECTION 106 OF THE RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) REQUIRE THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) TO CONDUCT SUPERFUND SITE INVESTIGATIONS AND ASSESSMENTS. THIS MANUAL PROVIDES GUIDANCE ON HOW TO CONDUCT THESE ASSESSMENTS. THE MANUAL IS DIVIDED INTO TWO MAIN PARTS: PART 1, WHICH DESCRIBES THE GENERAL PRINCIPLES OF SUPERFUND ASSESSMENTS, AND PART 2, WHICH PROVIDES DETAILED PROCEDURES FOR CONDUCTING ASSESSMENTS. PART 1 INCLUDES CHAPTERS ON THE SUPERFUND PROGRAM, THE ASSESSMENT PROCESS, AND THE ASSESSMENT REPORT. PART 2 INCLUDES CHAPTERS ON THE ASSESSMENT OF AIR, WATER, AND SOIL CONTAMINATION, AND THE ASSESSMENT OF HUMAN EXPOSURE TO CONTAMINANTS. THE MANUAL IS INTENDED TO BE USED BY EPA REGIONAL OFFICES, STATE DEPARTMENTS OF ENVIRONMENT, AND OTHER AGENCIES INVOLVED IN SUPERFUND SITE INVESTIGATIONS AND ASSESSMENTS.

quantified property values. These data are available for many chemicals that may be present at uncontrolled hazardous waste sites, and are found in various chemical reference texts. In cases where chemical data are missing, the analyst must estimate the property values. This section provides equations for estimating certain requisite chemical properties. Comprehensive guidance for chemical property estimation is provided in reference materials such as Lyman et al. (1982). Readily accessible computerized systems are available to predict a range of pertinent chemical properties. The computerized Graphic Exposure Modeling System (GEMS), and its subsystem CHEMEST, is an example. The EPA Office of Toxic Substances in Washington, D.C., has developed and is managing this system. Essentially a computerized version of Lyman et al. (1982), it can be rapidly accessed to estimate the chemical characteristics necessary for volatilization estimation.

The user of this manual can refer to Farino et al. (1983) for a detailed review and evaluation of existing equations for estimating volatilization from uncontrolled hazardous waste sites. This report presents a survey of available air release models for volatile substances and a critical analysis of the applications and limitations of each.

#### (1) Landfills Without Internal Gas Generation

Equation 2-3 can be used to estimate volatile releases from covered landfills containing toxic materials alone, or toxic materials segregated from other landfilled nonhazardous wastes. Equations 2-4 through 2-7 are used to calculate certain input variables that are required to apply Equation 2-3. Farmer et al. (1978) developed an equation to estimate the effectiveness of various landfill cover types and depths in controlling volatile releases. This equation, based on Fick's First Law of steady state diffusion, assumes that diffusion into the atmosphere occurs at a plane surface where concentrations remain constant. It ignores biodegradation, transport in water, adsorption, and production of landfill gas. Diffusion of the toxic vapor through the soil cover is the controlling factor. It also assumes that there is a sufficient mass of toxicant in the landfill so that depletion of the contaminant will not reduce the emission rate.

Equation 2-3, simplified by Farmer et al. (USEPA 1980b), incorporates a number of assumptions (see Farino et al. 1983 for a complete discussion), such as completely dry soil (worst case) and zero

concentration of volatilizing material at the soil surface. Shen (1981) converted Farmer's simplified equation for calculating the vapor flux rate to a form that provides a toxic vapor emission rate by multiplying the basic equation by the exposed contaminated surface area. In addition, Shen modified the equation to allow calculation of the volatilization rate of a specific component of the overall toxic mixture by multiplying by the weight fraction of the component in the mixture. However, as pointed out by Farino et al. (1983), a more accurate approach would be to multiply by the mole fraction of the toxic component in the buried mixture. Thus, Farmer's equation, as modified by Shen (1981) and Farino et al. (1983), is:

$$E_i = D_i C_{si} A \left( P_t^{1/3} \right) \frac{M_i}{d_{sc}} \quad (2-3)$$

where

- $E_i$  = emission rate of component  $i$ , (g/sec).
- $D_i$  = diffusion coefficient of component  $i$  in air, ( $\text{cm}^2/\text{sec}$ ).
- $C_{si}$  = saturation vapor concentration of component  $i$ , ( $\text{g}/\text{cm}^3$ ).
- $A$  = exposed area, ( $\text{cm}^2$ ).
- $P_t$  = total soil porosity, (dimensionless).
- $M_i$  = mole fraction of toxic component  $i$  in the waste, ( $\text{gmole}/\text{gmole}$ ).
- $d_{sc}$  = effective depth of soil cover, (cm).

Note that total soil porosity, rather than air-filled soil porosity, is used in this equation. The presence of water in a soil cover will tend to decrease the flux rate of a volatile compound by effectively decreasing the porosity, and also by increasing the geometric complexity of the soil pore system (because water adheres to soil particles), thus effectively increasing the vapor path (USEPA 1980b). Farmer et al. suggest, however, that when using their equation to design a landfill cover, the total porosity value be used (USEPA 1980b), thereby designing for the worst case (i.e., dry conditions). In most instances, it will be appropriate to apply this same worst-case logic to the analysis of volatilization release from landfilled wastes, assume that landfill cover soils are dry, and use a value for total porosity in Equation 2-3. It is recognized, however, that there may be situations where it can be shown that cover soils exist in a wet condition more often than in a dry one. In these cases, the air-filled soil porosity ( $P_a$ ) may be more appropriate, and this value can be substituted for  $P_t$  in Equation 2-3 when analyzing volatilization release.

If not provided in existing literature,  $D_i$ , a compound's diffusion coefficient (required for the above equation), can be calculated by Fuller's Method (Perry and Chilton 1973):

\* Although computerized dispersion modeling can be used to obtain contaminant release rates, it is primarily a tool for determining contaminant atmospheric fate. Thus, refer to Chapter 3, Environmental Fate Analysis, for detailed discussions of air dispersion models applicable to uncontrolled hazardous waste facilities.



$$D_i = \frac{0.001T^{1.75} \sqrt{\frac{1}{MW_i} + \frac{1}{MW_a}}}{P_a [\Sigma V_i]^{1.3} + [\Sigma V_a]^{1.3}} \quad (2-4)$$

where

- $T$  = absolute temperature, (°K).  
 $MW_i, MW_a$  = molecular weights of toxic substance and air (28.8), respectively, (g mole).  
 $P_a$  = absolute pressure, (atm).  
 $\Sigma V_i, \Sigma V_a$  = molecular diffusion volumes of toxic substance and air (20.1). This is the sum of the atomic diffusion volumes of the compound components, (cm<sup>3</sup> mole).

To estimate short-term (maximum) release rates, use a value for the temperature that reflects the expected summer maximum temperatures. Annual average temperatures should be used to initially estimate long-term (average) release rates. This initial estimated long-term release value will be revised as described in Section 2.3.3 to develop final long-term release estimates.

Relevant atomic diffusion volumes for use in estimating  $D_i$  are (Perry and Chilton 1973):

C = 16.5	Cl = 19.5	Aromatic ring	= -20.2
H = 1.98	Br = 35.0	Heterocyclic ring	= -20.2
O = 5.48	F = 25.0*		
N = 5.69	S = 17.0		

Table 2-3 presents diffusion coefficients that have been calculated for a variety of compounds, some of which may be present at abandoned sites.

An alternative method (Shen 1981) for approximating  $D_i$  involves the identification of a compound listed in Table 2-3 that has a molecular weight and molecular diffusion volume (calculated) similar to those of the toxic substance under evaluation. The unknown diffusion coefficient can then be calculated using:

$$D_i = D' \left( \frac{MW'}{MW_i} \right)^{\frac{1}{2}} \quad (2-5)$$

where

- $D_i$  = diffusion coefficient of the compound to be estimated from the known  $D'$ .  
 $D'$  = diffusion coefficient of a compound that can be found in the table, the molecular

- weight and atomic diffusion volume of which are close to that of the unknown.  
 $MW'$  = molecular weight of the selected compound  $D'$ .  
 $MW$  = molecular weight of the compound to be estimated.

Total soil porosity,  $P_t$ , can be calculated as follows (USEPA 1980b):

$$P_t = 1 - \frac{\beta}{\rho} \quad (2-6)$$

where

- $P_t$  = total soil porosity, (dimensionless).  
 $\beta$  = soil bulk density,\* (g cm<sup>3</sup>); generally between 1.0 and 2.0 g cm<sup>3</sup>.  
 $\rho$  = particle density, (g cm<sup>3</sup>); usually 2.65 g/cm<sup>3</sup> used for most mineral material.

For estimation,  $P_t$  can be assumed to be approximately 0.55 for dry, non-compacted soils, and about 0.35 for compacted soils. This same value (0.35) is also appropriate for use as a generic air-filled soil porosity ( $P_a$ ) when analyzing the volatilization release from soils with a high moisture content (Shen 1981). Alternatively, the local Soil Conservation Service office can be contacted to obtain site-specific estimated air-filled soil porosity values for specific locations.

Saturation vapor concentration,  $C_{si}$ , can be determined by (USEPA 1980b):

$$C_{si} = \frac{pMW_i}{RT} \quad (2-7)$$

where

- $C_{si}$  = saturation vapor concentration of component  $i$ , (g cm<sup>3</sup>).  
 $p$  = vapor pressure of the chemical,\* (mm Hg).  
 $MW_i$  = mole weight of component  $i$ , (g mole).  
 $R$  = molar gas constant, (62,361 mm Hg-cm<sup>3</sup> mole<sup>-1</sup> °K).  
 $T$  = absolute temperature, (°K).

Again, use maximum summer temperatures to estimate short-term release and annual average temperatures to initially estimate long-term release.

\* This value is from Shen (1981).

\* Values for soil bulk density for specified locations can be obtained from the U.S. Soil Conservation Service, Soils 5 File data base.

\* If the vapor pressure of a chemical under consideration is not available in standard reference texts, estimate it as described in Lyman et al. (1982).

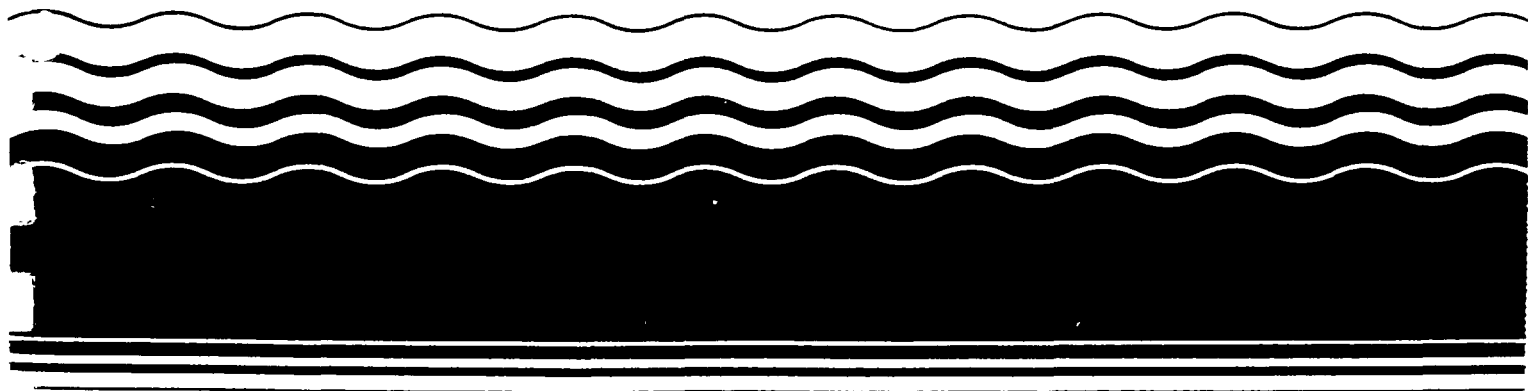


# Risk Assessment Guidance for Superfund:

PB 92-965533 -

Volume I –  
Human Health Evaluation  
Manual (Part B,  
Development of Risk-based  
Preliminary Remediation  
Goals)

Interim



A chemical-specific value for VF is used in the standard default equation (Equations (5), (6), (7), and (7) in Section 3.2.2) and is developed in Equation (8). The VF value calculated using Equation (8) has been developed for specific use in the other equations in this guidance; it may not be applicable in other technical contexts. Equation (8) lists the standard default parameters for calculating VF. If site-specific information is available, Equation (8) may be modified to calculate a VF that is more appropriate for the particular site. Supporting references should be consulted when substituting site-specific data to ensure that the model and specific parameters can be appropriately applied to the given site.

### 3.3.2 PARTICULATE EMISSION FACTOR

The particulate emission factor (PEF) relates the contaminant concentration in soil with the concentration of respirable particles (PM<sub>10</sub>) in the air due to fugitive dust emissions from surface contamination sites. This relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g., years). The particulate emissions from contaminated sites are due to wind erosion and, therefore, depend on the erodibility of the surface

#### SOIL-TO-AIR VOLATILIZATION FACTOR

$$VF (m^3/kg) = \frac{(LS \times V \times DH)}{A} \times \frac{(3.14 \times \alpha \times T)^{0.5}}{(2 \times D_e \times E \times K_{ow} \times 10^{-3} \text{ kg/g})} \quad (8)$$

where:

$$\alpha (cm^2/s) = \frac{(D_e \times E)}{E + (p_s)(1-E)K_{ow}}$$

Standard default parameter values that can be used to reduce Equation (8) are listed below. These represent "typical" values as identified in a number of sources. For example, when site-specific values are not available, the length of a side of the contaminated area (LS) is assumed to be 45 m; this is based on a contaminated area of 0.5 acre which approximates the size of an average residential lot. The "typical" values LS, DH, and V are from EPA 1986. "Typical" values for E, OC, and  $p_s$  are from EPA 1984, EPA 1988b, and EPA 1988f. Site-specific data should be substituted for the default values listed below wherever possible. Standard values for chemical-specific  $D_e$ ,  $H$ , and  $K_{ow}$  can be obtained by calling the Superfund Health Risk Technical Support Center.

Parameter	Definition (units)	Default
VF	volatilization factor (m <sup>3</sup> /kg)	—
LS	length of side of contaminated area (m)	45 m
V	wind speed in mixing zone (m/s)	2.25 m/s
DH	diffusion height (m)	2 m
A	area of contamination (cm <sup>2</sup> )	20,250,000 cm <sup>2</sup>
$D_e$	effective diffusivity (cm <sup>2</sup> /s)	$D_e \times E^{0.53}$
E	true soil porosity (unitless)	0.35
$K_{ow}$	soil/air partition coefficient (g soil/cm <sup>3</sup> air)	$(H/K_d) \times 41$ , where 41 is a units conversion factor
$p_s$	true soil density or particulate density (g/cm <sup>3</sup> )	2.65 g/cm <sup>3</sup>
T	exposure interval (s)	$7.9 \times 10^8$ s
$D_i$	molecular diffusivity (cm <sup>2</sup> /s)	chemical-specific
H	Henry's law constant (atm-m <sup>3</sup> /mol)	chemical-specific
$K_d$	soil-water partition coefficient (cm <sup>3</sup> /g)	chemical-specific, or $K_{ow} \times OC$
$K_{oc}$	organic carbon partition coefficient (cm <sup>3</sup> /g)	chemical-specific
OC	organic carbon content of soil (fraction)	site-specific, or 0.02

45 m  
5.06  
5.4 x 10<sup>8</sup>



## Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites<sup>1</sup>

This emergency standard is under the jurisdiction of ASTM Committee E1 on Environmental Assessment and is the direct responsibility of Subcommittee E1.3.3 on Storage Tanks.

### 1. Scope

1.1 This guide covers risk-based corrective action (RBCA), that is a consistent decision-making process for the assessment and response to subsurface contamination, based on the protection of human health and environmental resources. Sites with subsurface contamination vary greatly in terms of complexity, physical and chemical characteristics, and in the risk that they may pose to human health and environmental resources. The RBCA process recognizes this diversity, and utilizes a tiered approach where assessment and remediation activities are appropriately tailored to site-specific conditions and risks. This flexibility allows RBCA to be more cost-effective than traditional approaches under which all sites conform to uniform standards and procedures. While the RBCA process is not limited to a particular class of compounds, this guide emphasizes the application of RBCA to petroleum fuel releases.

1.2 The decision process described in this guide integrates risk and exposure assessment practices, as suggested by the United States Environmental Protection Agency (USEPA), with site assessment activities and remedial measure selection to ensure that the chosen action is protective of human health and environmental resources. The following general sequence of events is prescribed in RBCA, once the process is triggered by the suspicion or confirmation of hazardous hydrocarbon levels:

1.2.1 A Tier 1, or preliminary site assessment,

1.2.2 Classification of the site by the urgency of initial response,

1.2.3 Implementation of an initial response action appropriate for the selected site classification,

1.2.4 Comparison of site conditions with Tier 1 screening levels given in an evergreen "look-up" table containing conservative risk-based screening levels and other relevant criteria (drinking water standards, aesthetic criteria, ecological criteria, etc.),

1.2.5 Deciding if Tier 1 screening target levels are appropriate, and if not,

1.2.5.1 Collect additional site-specific information as required, and

1.2.5.2 Develop site-specific target levels and points of compliance (Tiers 2 and 3),

1.2.6 Comparison of the negotiated target levels with site conditions at the appropriate points of compliance, and if any exceptions are noted,

1.2.6.1 Develop a corrective action plan to achieve the negotiated target levels in an appropriate time period (based on risks posed by the site). Alternatives to be considered include combinations of traditional remedial methods (for example, excavation, pump and treat, and soil vapor extraction) with institutional controls and natural attenuation.

1.3 This guide describes the previously outlined process in more detail. For those interested only in becoming familiar with RBCA, the short main body of text provides a brief overview of the RBCA process (see Section 4), and then presents RBCA procedures in a step-by-step fashion (see Section 5) followed by a discussion of ways in which the process can be misapplied (see Section 6). For those interested in additional background information, appendices have been included. These are focused on the following:

1.3.1 Characteristics of petroleum fuels (see Appendix X1),

1.3.2 Derivation of the example Tier 1 RBSL Look-Up Table (see Appendix X2),

1.3.3 Uses of predictive modeling relative to the RBCA process (see Appendix X3),

1.3.4 Considerations for institutional controls (see Appendix X4), and

1.3.5 RBCA examples (Appendix X5).

1.4 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Significance and Use

2.1 The allocation of limited resources (for example, time, money, regulatory oversight, qualified professionals) to any one petroleum release site necessarily influences corrective action decisions at other sites. This has spurred the search for innovative and cost-effective approaches to corrective action decision making, that still ensures that human health and environmental resources are protected.

2.2 The RBCA process presented in this guide is a rational, and consistent, streamlined decision process for selecting appropriate corrective actions at petroleum release sites. Advantages of the RBCA approach are as follows:

2.2.1 Decisions are based on reducing the risk of adverse human or environmental impacts to appropriate levels.

2.2.2 Assurance that site assessment activities are focused on collecting only that information that is necessary to making risk-based corrective action decisions.

2.2.3 Assurance that limited resources are focused toward those sites that pose the greatest risk to human health

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misused, as proposed remediation "standards." The reader should note that not all possible pathways have been considered and a number of assumptions concerning exposure scenarios and parameter values have been made. These should be reviewed for appropriateness before using the listed RBSLs as Tier 1 screening values.

X2.1.2 The approaches used to calculate RBSLs appearing in Table X2.1 are briefly discussed for exposure to

vapors, ground water, surficial soils, and ambient air by means of the following pathways:

X2.1.2.1 Inhalation of vapors

X2.1.2.2 Ingestion of ground water

X2.1.2.3 Inhalation of indoor vapors originating from dissolved hydrocarbons in ground water

X2.1.2.4 Inhalation of indoor vapors originating from dissolved hydrocarbons in ground water

TABLE X2.1 Volatilization Factors (VF), Leaching Factor (LF<sub>gw</sub>), and Effective Diffusion Coefficients (D<sub>eff</sub>)

Symbol	Cross-Media Route or Definition	Equation
$VF_{\text{enc}}^{\text{gw}}$	Ground water → enclosed-space vapors	$VF_{\text{enc}}^{\text{gw}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{L}-\text{H}_2\text{O})} \right] = \frac{\left[ \frac{D_{\text{eff}}^{\text{enc}}}{EA(L_{\text{enc}})} \right]}{1 + \left[ \frac{D_{\text{eff}}^{\text{enc}}(L_{\text{enc}})}{EA(L_{\text{enc}})} \right] + \left[ \frac{D_{\text{eff}}^{\text{enc}}(L_{\text{enc}})}{10D_{\text{eff}}^{\text{gw}}(L_{\text{enc}})} \right]} \times 10^{-3} \frac{\text{cm}^2}{\text{m}^2}$
$VF_{\text{amb}}^{\text{gw}}$	Ground water → ambient (outdoor) vapors	$VF_{\text{amb}}^{\text{gw}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{L}-\text{H}_2\text{O})} \right] = \frac{H}{1 + \left[ \frac{U_{\text{amb}}(L_{\text{amb}})}{WD_{\text{amb}}} \right]} \times 10^{-3} \frac{\text{cm}^2}{\text{m}^2}$
$VF_{\text{ss}}^{\text{ss}}$	Surficial soils → ambient air (vapors)	$VF_{\text{ss}}^{\text{ss}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{2W_{\text{ss}}}{U_{\text{amb}}^{\text{ss}}} \sqrt{\frac{D_{\text{eff}}^{\text{ss}}}{\pi(\delta_{\text{ss}} + \kappa_{\text{ss}}\rho_{\text{ss}} + H\delta_{\text{amb}})}} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{m}^2\text{-g}}$ or $VF_{\text{ss}}^{\text{ss}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{W_{\text{ss}}\delta}{U_{\text{amb}}^{\text{ss}}} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{m}^2\text{-g}} \text{ whenever } \delta \text{ less}^{\text{a}}$
$VF_{\text{ss}}^{\text{p}}$	Surficial soils → ambient air (particulates)	$VF_{\text{ss}}^{\text{p}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{\rho_{\text{ss}}W}{U_{\text{amb}}^{\text{ss}}} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{m}^2\text{-g}} \text{ e}$
$VF_{\text{amb}}^{\text{ss}}$	Subsurface soils → ambient air	$VF_{\text{amb}}^{\text{ss}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{H_{\text{ss}}}{(\delta_{\text{ss}} + \kappa_{\text{ss}}\rho_{\text{ss}} + H\delta_{\text{amb}}) \left( 1 + \frac{U_{\text{amb}}(L_{\text{amb}})}{D_{\text{eff}}^{\text{ss}}W} \right)} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{m}^2\text{-g}}$
$VF_{\text{enc}}^{\text{ss}}$	Subsurface soil → enclosed-space vapors	$VF_{\text{enc}}^{\text{ss}} \left[ \frac{(\text{mg}/\text{m}^3\text{-air})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{H_{\text{ss}} \left[ \frac{D_{\text{eff}}^{\text{ss}}(L_{\text{ss}})}{EA(L_{\text{ss}})} \right]}{1 + \left[ \frac{D_{\text{eff}}^{\text{ss}}(L_{\text{ss}})}{EA(L_{\text{ss}})} \right] + \left[ \frac{D_{\text{eff}}^{\text{ss}}(L_{\text{ss}})}{10D_{\text{eff}}^{\text{gw}}(L_{\text{enc}})} \right]} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{m}^2\text{-g}}$
$LF_{\text{gw}}^{\text{ss}}$	Subsurface soils → ground water	$LF_{\text{gw}}^{\text{ss}} \left[ \frac{(\text{mg}/\text{L}-\text{H}_2\text{O})}{(\text{mg}/\text{kg}-\text{soil})} \right] = \frac{\rho_{\text{ss}}}{(\delta_{\text{ss}} + \kappa_{\text{ss}}\rho_{\text{ss}} + H\delta_{\text{amb}}) \left( 1 + \frac{U_{\text{amb}}(L_{\text{amb}})}{H\delta_{\text{ss}}} \right)} \times 10^3 \frac{\text{cm}^2\text{-kg}}{\text{L-g}}$
$D_{\text{eff}}^{\text{ss}}$	Effective diffusion coefficient in soil based on vapor-phase concentration	$D_{\text{eff}}^{\text{ss}} \left[ \frac{(\text{cm}^2)}{\text{s}} \right] = D_{\text{eff}}^{\text{ss}} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}} + D_{\text{eff}}^{\text{ss}} \frac{1}{H} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}}$
$D_{\text{eff}}^{\text{crack}}$	Effective diffusion coefficient through foundation cracks	$D_{\text{eff}}^{\text{crack}} \left[ \frac{(\text{cm}^2)}{\text{s}} \right] = D_{\text{eff}}^{\text{ss}} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}} + D_{\text{eff}}^{\text{ss}} \frac{1}{H} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}}$
$D_{\text{eff}}^{\text{cap}}$	Effective diffusion coefficient through capillary fringe	$D_{\text{eff}}^{\text{cap}} \left[ \frac{(\text{cm}^2)}{\text{s}} \right] = D_{\text{eff}}^{\text{ss}} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}} + D_{\text{eff}}^{\text{ss}} \frac{1}{H} \frac{\delta_{\text{ss}}}{\delta_{\text{ss}}}$
$D_{\text{eff}}^{\text{gw}}$	Effective diffusion coefficient between ground water and soil surface	$D_{\text{eff}}^{\text{gw}} \left[ \frac{(\text{cm}^2)}{\text{s}} \right] = D_{\text{eff}}^{\text{ss}} + \gamma_{\text{ss}} \left[ \frac{D_{\text{eff}}^{\text{ss}}}{D_{\text{eff}}^{\text{ss}}} + \frac{D_{\text{eff}}^{\text{ss}}}{D_{\text{eff}}^{\text{ss}}} \right]$
$C_{\text{ss}}^{\text{sat}}$	Soil concentration at which dissolved pore-water and vapor phases become saturated	$C_{\text{ss}}^{\text{sat}} \left[ \frac{\text{mg}}{\text{kg}-\text{soil}} \right] = \frac{1}{\rho_{\text{ss}}} \times (H\delta_{\text{ss}} + \delta_{\text{ss}} + \kappa_{\text{ss}}\rho_{\text{ss}}) \times 10^3 \frac{\text{L-g}}{\text{cm}^3\text{-kg}}$

<sup>a</sup> See Ref (18).

<sup>b</sup> See Ref (18).

<sup>c</sup> See Ref (19).

<sup>d</sup> Based on mass balance

<sup>e</sup> See Ref (20)

X2.1.2.5 Ingestion of surficial soil, inhalation of outdoor vapors and particulates emanating from surficial soils, and dermal absorption resulting from surficial soil contact with skin.

X2.1.2.6 Inhalation of outdoor vapors originating from non-hydrocarbons in subsurface soils.

X2.1.2.7 Inhalation of indoor air vapors originating from subsurface by hydrocarbons.

X2.1.2.8 Ingestion of ground water impacted by leaching of hydrocarbons from subsurface soils.

X2.1.3 For the pathways considered, approaches used in this appendix are consistent with guidelines contained in Ref. (1).

X2.1.4 The following development presented focuses only

on human-health RBSLs for chronic (long-term) exposure.

X2.1.4.1 In the case of compounds that have been classified as carcinogens, the RBSLs are based on the general equation

$$\text{risk} = \frac{\text{average intake (mg/kg-day)}}{\text{cancer slope factor (mg/kg-day)}^{-1}}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, etc.), the source concentration, and transport rates between the source and receptor. The potency factor is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (6) database, USEPA Health Effects Assessment Summary Tables (HEAST), (7), and peer-reviewed sources.

TABLE X2.2 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1—Carcinogenic Effects<sup>a</sup>

Note.—See Tables X2.3 through X2.6 for definition of parameters.

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	Inhalation <sup>b</sup>	$RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3\text{-air}} \right] = \frac{TR \times BW \times AT_e \times 365 \frac{\text{days}}{\text{years}} \times 10^{-3} \frac{\text{mg}}{\text{g}}}{SF_a \times IR_{air} \times EF \times ED}$
Ground water	Ingestion (potable ground water supply only) <sup>b</sup>	$RBSL_{gw} \left[ \frac{\text{mg}}{\text{L-H}_2\text{O}} \right] = \frac{TR \times BW \times AT_e \times 365 \frac{\text{days}}{\text{years}}}{SF_g \times IR_{gw} \times EF \times ED}$
Ground water <sup>c</sup>	Enclosed-space (indoor) vapor inhalation <sup>b</sup>	$RBSL_{gw} \left[ \frac{\text{mg}}{\text{L-H}_2\text{O}} \right] = \frac{RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3\text{-air}} \right]}{VF_{indoor}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$
Ground water <sup>c</sup>	Ambient (outdoor) vapor inhalation <sup>b</sup>	$RBSL_{gw} \left[ \frac{\text{mg}}{\text{L-H}_2\text{O}} \right] = \frac{RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3\text{-air}} \right]}{VF_{ambient}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$
Surficial soil	Ingestion of soil, inhalation of vapors and particulates, and dermal contact <sup>b</sup>	$RBSL_s \left[ \frac{\mu\text{g}}{\text{kg-soil}} \right] = \frac{TR \times BW \times AT_e \times 365 \frac{\text{days}}{\text{years}}}{EF \times ED \left[ \left( SF_g \times 10^{-6} \frac{\text{kg}}{\text{mg}} \times IR_{soil} \times RAF_g + GA \times M \times RAF_g \right) + (SF_a \times IR_{air} \times (VF_{indoor} + VF_{amb})) \right]}$ For surficial and excavated soils (0 to 1 m)
Subsurface soil <sup>c</sup>	Ambient (outdoor) vapor inhalation <sup>b</sup>	$RBSL_s \left[ \frac{\text{mg}}{\text{kg-soil}} \right] = \frac{RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3\text{-air}} \right]}{VF_{ambient}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$
Subsurface soil <sup>c</sup>	Enclosed space (indoor) vapor inhalation <sup>b</sup>	$RBSL_s \left[ \frac{\text{mg}}{\text{kg-soil}} \right] = \frac{RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3\text{-air}} \right]}{VF_{indoor}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$
Subsurface soil <sup>c</sup>	Leaching to ground water <sup>b</sup>	$RBSL_s \left[ \frac{\text{mg}}{\text{kg-soil}} \right] = \frac{RBSL_{gw} \left[ \frac{\text{mg}}{\text{L-H}_2\text{O}} \right]}{LF_{gw}}$

<sup>a</sup> Note that all RBSL values should be compared with thermodynamic partitioning limits, such as 30,000:1 (air) maximum vapor concentrations, etc. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

<sup>b</sup> Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, etc.) can be derived with these equations by substituting the selected target level for  $RBSL_{air}$  or  $RBSL_{gw}$  appearing in these equations.

<sup>c</sup> These equations are based on Ref. (1).

<sup>d</sup> These equations employ the "cross-media partitioning factors,"  $VF_a$  and  $VF_{amb}$ .

TABLE X2.3 Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table X2.1: Noncarcinogenic Effects<sup>a</sup>

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	inhalation <sup>b</sup>	$RBSL_{air} \left[ \frac{\mu g}{m^3 \cdot air} \right] = \frac{THQ \times RfD \times BW \times AT_n \times 365 \frac{days}{years} \times 10^{-6} \frac{mg}{\mu g}}{R_{air} \times EF \times ED}$
Ground water	ingestion (potable ground water supply only) <sup>c</sup>	$RBSL_{gw} \left[ \frac{mg}{L \cdot H_2O} \right] = \frac{THQ \times RfD \times BW \times AT_n \times 365 \frac{days}{years}}{R_{gw} \times EF \times ED}$
Ground water <sup>d</sup>	Enclosed-space (indoor) vapor inhalation <sup>e</sup>	$RBSL_{gw} \left[ \frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[ \frac{\mu g}{m^3 \cdot air} \right]}{VF_{encld}} \times 10^{-3} \frac{mg}{\mu g}$
Ground water <sup>d</sup>	Ambient (outdoor) vapor inhalation <sup>e</sup>	$RBSL_{gw} \left[ \frac{mg}{L \cdot H_2O} \right] = \frac{RBSL_{air} \left[ \frac{\mu g}{m^3 \cdot air} \right]}{VF_{ambd}} \times 10^{-3} \frac{mg}{\mu g}$
Soil	ingestion of soil, inhalation of vapors and particulates, and dermal contact <sup>f</sup>	$RBSL_{soil} \left[ \frac{\mu g}{kg \cdot soil} \right] = \frac{THQ \times BW \times AT_n \times 365 \frac{days}{years}}{EF \times ED \times \left( 10^{-3} \frac{kg}{mg} \times (IR_{soil} \times RAF_g + SA \times M \times RAF_d) \right) \times \left( \frac{R_{air}}{RfD} \times VF_{air} + VF_{gw} \right)}$ <p>For surficial and excavated soils (0 to 1 m)</p>
Subsurface soil <sup>d</sup>	Ambient (outdoor) vapor inhalation <sup>e</sup>	$RBSL_{soil} \left[ \frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[ \frac{\mu g}{m^3 \cdot air} \right]}{VF_{ambd}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil <sup>d</sup>	Enclosed space (indoor) vapor inhalation <sup>e</sup>	$RBSL_{soil} \left[ \frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{air} \left[ \frac{\mu g}{m^3 \cdot air} \right]}{VF_{encld}} \times 10^{-3} \frac{mg}{\mu g}$
Subsurface soil <sup>d</sup>	Leaching to ground water <sup>g</sup>	$RBSL_{soil} \left[ \frac{mg}{kg \cdot soil} \right] = \frac{RBSL_{gw} \left[ \frac{mg}{L \cdot H_2O} \right]}{LF_{gw}}$

<sup>a</sup> Note that all RBSL values should be compared with thermodynamic partitioning limits, such as solubility levels, maximum vapor concentrations, etc. If a RBSL exceeds the relevant partitioning limit, this is an indication that the selected risk or hazard level will never be reached or exceeded for that chemical and the selected exposure scenario.

<sup>b</sup> Screening levels for these media based on other considerations (for example, aesthetic, background levels, environmental resource protection, etc.) can be derived with these equations by substituting the selected target level for  $RBSL_{air}$  or  $RBSL_{gw}$  appearing in these equations.

<sup>c</sup> These equations are based on  $Rf$  (1).

<sup>d</sup> These equations simply define the "cross-media partitioning factors,"  $VF_{air}$  and  $LF_{gw}$ .

The RBSL values appearing in Table X2.1 correspond to probabilities of adverse health effects ("risks") in the range from  $10^{-6}$  to  $10^{-4}$  resulting from the specified exposure. Note that this risk value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential risk to a population for these RBSLs is lower than the  $10^{-6}$  to  $10^{-4}$  range.

X2.1.4.2 In the case of compounds that have not been classified as carcinogens, the RBSLs are based on the general equation:

$$\text{hazard quotient} = \frac{\text{average intake (mg/kg-day)}}{\text{reference dose (mg/kg-day)}}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, etc.), the source concentration, and transport rates between the source and receptor. The reference dose is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) (6) database, USEPA Health Effects Assessment Summary Tables (HEAST) (7), and peer-reviewed sources. RBSL values appearing in Table X2.1 correspond to hazard quotients of unity resulting from the specified exposure. Note that this hazard quotient value does not reflect the probability for the specified exposure scenario to occur. Therefore, the actual potential impact to a population for



TABLE X2.4 Exposure Parameters Appearing in Tables X2.2 and X2.3

Parameter	Definitions (Units)	Residential	Commercial/Industrial
AT <sub>c</sub>	Averaging time for carcinogens (years)	70 years	35 years <sup>a</sup>
AT <sub>n</sub>	Averaging time for non-carcinogens (years)	30 years	25 years <sup>a</sup>
BW	Adult body weight (kg)	70 kg	70 kg <sup>a</sup>
ED	Exposure duration (years)	30 years	25 years <sup>a</sup>
EF	Exposure frequency (days/year)	350 days/year	350 days/year <sup>a</sup>
R <sub>soil</sub>	Soil ingestion rate (mg/day)	100 mg/day	50 mg/day <sup>a</sup>
R <sub>soil, indoor</sub>	Daily indoor inhalation rate (m <sup>3</sup> /day)	15 m <sup>3</sup> /day	20 m <sup>3</sup> /day <sup>a</sup>
R <sub>soil, outdoor</sub>	Daily outdoor inhalation rate (m <sup>3</sup> /day)	20 m <sup>3</sup> /day	20 m <sup>3</sup> /day <sup>a</sup>
R <sub>water</sub>	Daily water ingestion rate (L/day)	2 L/day	1 L/day <sup>a</sup>
LF <sub>soil</sub>	Leaching factor (mg/L H <sub>2</sub> O)/(mg/kg soil)—see Table X2.5	Chemical-specific	Chemical-specific
M	Dermal skin adherence factor (mg/cm <sup>2</sup> )	0.5	0.5 <sup>a</sup>
RAF <sub>c</sub>	Dermal relative absorption factor (volatiles, PAHs)	0.5/0.05	0.5/0.05 <sup>a</sup>
RAF <sub>n</sub>	Der. relative absorption factor	1.0	1.0
RBSL	Risk-based screening level for media: (mg/kg soil)/(mg/L H <sub>2</sub> O) or (μg/m <sup>3</sup> air)	Chemical-, media-, and exposure route-specific	Chemical-, media-, and exposure route-specific
RfD	Inhalation chronic reference dose (mg/kg-day)	Chemical-specific	Chemical-specific
RfD <sub>o</sub>	Oral chronic reference dose (mg/kg-day)	Chemical-specific	Chemical-specific
SA	Skin surface area (cm <sup>2</sup> /day)	3160	3160 <sup>a</sup>
SF	Inhalation cancer slope factor ((mg/kg-day) <sup>-1</sup> )	Chemical-specific	Chemical-specific
SF <sub>o</sub>	Oral cancer slope factor ((mg/kg-day) <sup>-1</sup> )	Chemical-specific	Chemical-specific
THQ	Target hazard quotient for individual constituents (unitless)	1.0	1.0
TR	Target excess individual lifetime cancer risk (unitless)	for example, 10 <sup>-6</sup> or 10 <sup>-4</sup>	for example, 10 <sup>-6</sup> or 10 <sup>-4</sup>
VF	Volatilization factor (mg/m <sup>3</sup> air)/(mg/kg soil) or (mg/m <sup>3</sup> air)/(mg/L H <sub>2</sub> O)—see Table X2.1	Chemical- and media-specific	Chemical- and media-specific

<sup>a</sup> See Ref. (8).

<sup>b</sup> See Ref. (15).

TABLE X2.5 Soil, Building, Surface, and Subsurface Parameters Used in Generating Example Tier 1 RBSLs

Note—See X2.10 for justification of parameter selection.

Parameters	Definitions (Units)	Residential	Commercial/Industrial
D	Lower depth of surficial soil zone (cm)	100 cm	100 cm
D <sub>air</sub>	Diffusion coefficient in air (cm <sup>2</sup> /s)	Chemical-specific	Chemical-specific
D <sub>water</sub>	Diffusion coefficient in water (cm <sup>2</sup> /s)	Chemical-specific	Chemical-specific
ER	Enclosed-space air exchange rate (1/s)	0.00014 s <sup>-1</sup>	0.00023 s <sup>-1</sup>
f <sub>oc</sub>	Fraction of organic carbon in soil (g-C/g-soil)	0.01	0.01
H	Henry's law constant (cm <sup>3</sup> H <sub>2</sub> O)/(cm <sup>3</sup> air)	Chemical-specific	Chemical-specific
h <sub>cap</sub>	Thickness of capillary fringe (cm)	5 cm	5 cm
h <sub>v</sub>	Thickness of vadose zone (cm)	295 cm	295 cm
i	Infiltration rate of water through soil (cm/years)	30 cm/years	30 cm/years
K <sub>oc</sub>	Carbon-water sorption coefficient (g-H <sub>2</sub> O/g-C)	Chemical-specific	Chemical-specific
K <sub>s</sub>	Soil-water sorption coefficient (g-H <sub>2</sub> O/g-soil)	f <sub>oc</sub> × K <sub>oc</sub>	f <sub>oc</sub> × K <sub>oc</sub>
L <sub>g</sub>	Enclosed-space volume/infiltration area ratio (cm)	200 cm	300 cm
L <sub>space</sub>	Enclosed-space foundation or wall thickness (cm)	15 cm	15 cm
L <sub>gw</sub>	Depth to ground water = h <sub>cap</sub> + h <sub>v</sub> (cm)	300 cm	300 cm
L <sub>s</sub>	Depth to subsurface soil sources (cm)	100 cm	100 cm
P <sub>e</sub>	Particulate emission rate (g/cm <sup>2</sup> ·s)	6.9 × 10 <sup>-14</sup>	6.9 × 10 <sup>-14</sup>
S	Pure component solubility in water (mg/L-H <sub>2</sub> O)	Chemical-specific	Chemical-specific
U <sub>air</sub>	Wind speed above ground surface in ambient mixing zone (cm/s)	225 cm/s	225 cm/s
U <sub>gw</sub>	Ground water Darcy velocity (cm/s)	2500 cm/years	2500 cm/years
W	Width of source area parallel to wind, or ground water flow direction (cm)	1500 cm	1500 cm
z <sub>air</sub>	Ambient air mixing zone height (cm)	200 cm	200 cm
z <sub>gw</sub>	Ground water mixing zone thickness (cm)	200 cm	200 cm
α	Areal fraction of cracks in foundations/walls (cm <sup>2</sup> -cracks/cm <sup>2</sup> -total area)	0.01 cm <sup>2</sup> -cracks/cm <sup>2</sup> -total area	0.01 cm <sup>2</sup> -cracks/cm <sup>2</sup> -total area
θ <sub>cap</sub>	Volumetric air content in capillary fringe soils (cm <sup>3</sup> -air/cm <sup>3</sup> -soil)	0.038 cm <sup>3</sup> -air/cm <sup>3</sup> -soil	0.038 cm <sup>3</sup> -air/cm <sup>3</sup> -soil
θ <sub>crack</sub>	Volumetric air content in foundation/wall cracks (cm <sup>3</sup> -air/cm <sup>3</sup> total volume)	0.26 cm <sup>3</sup> -air/cm <sup>3</sup> total volume	0.26 cm <sup>3</sup> -air/cm <sup>3</sup> total volume
θ <sub>so</sub>	Volumetric air content in vadose zone soils (cm <sup>3</sup> -air/cm <sup>3</sup> -soil)	0.26 cm <sup>3</sup> -air/cm <sup>3</sup> -soil	0.26 cm <sup>3</sup> -air/cm <sup>3</sup> -soil
θ <sub>v</sub>	Total soil porosity (cm <sup>3</sup> /cm <sup>3</sup> -soil)	0.38 cm <sup>3</sup> /cm <sup>3</sup> -soil	0.38 cm <sup>3</sup> /cm <sup>3</sup> -soil
θ <sub>cap, w</sub>	Volumetric water content in capillary fringe soils (cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil)	0.342 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil	0.342 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil
θ <sub>crack, w</sub>	Volumetric water content in foundation/wall cracks (cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> total volume)	0.12 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> total volume	0.12 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> total volume
θ <sub>so, w</sub>	Volumetric water content in vadose zone soils (cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil)	0.12 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil	0.12 cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil
ρ <sub>s</sub>	Soil bulk density (g-soil/cm <sup>3</sup> -soil)	1.7 g/cm <sup>3</sup>	1.7 g/cm <sup>3</sup>
t	Averaging time for vapor flux (s)	9.46 × 10 <sup>4</sup> s	9.46 × 10 <sup>4</sup> s

these RBSLs is lower than a hazard quotient of unity.

X2.1.5 Tables X2.2 through X2.6 summarize the equations and parameters used to prepare the example look-up Table X2.1 appearing in the main body of this guide. The basis for each of these equations is discussed in X2.2 through X2.10.

#### X2.2 Air—Inhalation of Vapors (Outdoors/Indoors)

X2.2.1 In this case chemical intake results from the inhalation of vapors. It is assumed that vapor concentrations remain constant over the duration of exposure, and all inhaled chemicals are absorbed. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for vapor concentrations in the breathing zone follow guidance given in Ref. (1). Should the calculated RBSL exceed the saturated

TABLE X2.6 Chemical-Specific Properties Used in the Derivation Example Tier 1 RBSLs

Chemical	CAS Number	$M_w$ , g/mole	$H$ , L/m <sup>3</sup> L-H <sub>2</sub> O/air	$D_{air}$ , cm <sup>2</sup> /s	$D_{H_2O}$ , cm <sup>2</sup> /s	$\log K_{ow}$ , L/kg	$\log K_{oc}$ , L/kg
Benzene	71-43-2	78 <sup>a</sup>	0.22 <sup>a</sup>	0.093 <sup>a</sup>	$1.0 \times 10^{-5}$ <sup>a</sup>	1.68 <sup>a</sup>	0.10 <sup>a</sup>
Toluene	108-88-3	92 <sup>a</sup>	0.25 <sup>a</sup>	0.085 <sup>a</sup>	$0.4 \times 10^{-5}$ <sup>a</sup>	2.13 <sup>a</sup>	0.55 <sup>a</sup>
Ethyl benzene	103-41-4	106 <sup>a</sup>	0.32 <sup>a</sup>	0.075 <sup>a</sup>	$0.0 \times 10^{-5}$ <sup>a</sup>	1.84 <sup>a</sup>	0.33 <sup>a</sup>
Mixed xylenes	1330-20-7	106 <sup>a</sup>	0.29 <sup>a</sup>	0.070 <sup>a</sup>	$0.0 \times 10^{-5}$ <sup>a</sup>	2.08 <sup>a</sup>	0.26 <sup>a</sup>
Naphthalene	91-20-3	128 <sup>a</sup>	0.049 <sup>a</sup>	0.0720 <sup>a</sup>	$0.4 \times 10^{-5}$ <sup>a</sup>	3.11 <sup>a</sup>	0.28 <sup>a</sup>
Benz[a]pyrene	50-32-6	252 <sup>b</sup>	$1.4 \times 10^{-4}$ <sup>c</sup>	0.050 <sup>d</sup>	$0.0 \times 10^{-5}$ <sup>e</sup>	5.63 <sup>f</sup>	5.38 <sup>g</sup>
Chemical	CAS Number	$DF_w$ , kg-day/m <sup>2</sup>	$DF_w$ , kg-day/m <sup>2</sup>	$R_{D,w}$ , imp/kg-day	$R_{D,w}$ , mg/kg-day		
Benzene	71-43-2	0.003 <sup>f</sup>	0.003 <sup>f</sup>				
Toluene	108-88-3			0.2 <sup>f</sup>	0.11 <sup>f</sup>		
Ethyl benzene	103-41-4			0.1 <sup>f</sup>	0.05 <sup>f</sup>		
Mixed xylenes	1330-20-7			0.1 <sup>f</sup>	0.05 <sup>f</sup>		
Naphthalene	91-20-3			0.004 <sup>g</sup>	0.004 <sup>g</sup>		
Benz[a]pyrene	50-32-6	0.3 <sup>f</sup>	6.1 <sup>f</sup>				

<sup>a</sup> See Ref. (21)

<sup>b</sup> See Ref. (22)

<sup>c</sup> See Ref. (11)

<sup>d</sup> Diffusion coefficient calculated using the method of Fuller, Schettler, and Giddings, from Ref. (9)

<sup>e</sup> Calculated from  $K_{ow}/K_{oc}$  correlation:  $\log(K_{oc}) = 0.937 \log(K_{ow}) - 0.006$ , from Ref. (9)

<sup>f</sup> See Ref. (6)

<sup>g</sup> See Ref. (7)

vapor concentration for any individual component, "> $P_{air}$ " is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

**X2.3 Ground water—Ingestion of Ground water**—In this case chemical intake results from ingestion of ground water. It is assumed that the dissolved hydrocarbon concentrations remain constant over the duration of exposure. Equations appearing in Tables X2.2 and X2.3 for estimating RBSLs for drinking water concentrations follow guidance given in Ref. (1) for ingestion of chemicals in drinking water. Should the calculated RBSL exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (unless free-phase product is mixed with the ingested water).

**X2.4 Ground water—Inhalation of Outdoor Vapors**

**X2.4.1** In this case chemical intake is a result of inhalation of outdoor vapors which originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in X2.2. If the selected target vapor concentration is some value other than the RBSL for inhalation (that is, odor threshold or ecological criterion), this value can be substituted for the  $RBSL_{air}$  parameter appearing in the equations given in Tables X2.2 and X2.3.

**X2.4.2** A conceptual model for the transport of chemicals from ground water to ambient air is depicted in Fig. X2.1. For simplicity, the relationship between outdoor air and dissolved ground water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor,"  $VF_{amp}$  [(mg/m<sup>3</sup>-air)/(mg/L-H<sub>2</sub>O)], defined in Table X2.1. It is based on the following assumptions:

**X2.4.2.1** A constant dissolved chemical concentration in ground water,

**X2.4.2.2** Linear equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table,

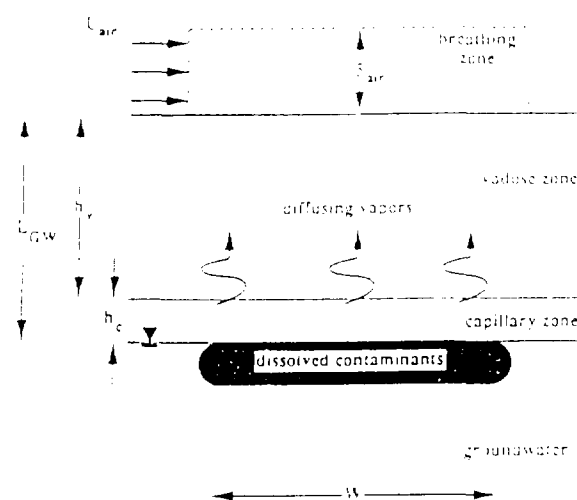


FIG. X2.1 Volatilization from Ground Water to Ambient Air

**X2.4.2.3** Steady-state vapor- and liquid-phase diffusion through the capillary fringe and vadose zones to ground surface,

**X2.4.2.4** No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

**X2.4.2.5** Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

**X2.4.3** Should the calculated  $RBSL_w$  exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

**X2.5 Ground water—Inhalation of Enclosed-Space (Indoor) Vapors**

**X2.5.1** In this case chemical intake results from the inhalation of vapors in enclosed spaces. The chemical vapors originate from dissolved hydrocarbons in ground water located some distance below ground surface. Here the goal is to determine the dissolved hydrocarbon RBSL that corresponds to the target RBSL for vapors in the breathing zone.

in Figure X2.1.1. In the event that the vapor concentration in air is lower than the  $RBSL_{air}$  for inhalation (that is, some amount  $d < 1$ ), additional information, this value can be substituted for the  $RBSL_{air}$  parameter appearing in the equations given in Table X2.2 and X2.3.

X2.5.2.1 A conceptual model for the transport of chemicals from ground water to air is depicted in Fig. X2.2.1. For simplicity, the relationship between outdoor-air and dissolved ground-water concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor"  $V/F_{air}$ ,  $[(\text{mg}/\text{m}^3\text{-air})/(\text{mg}/\text{L-H}_2\text{O})]$  defined in Table X2.1. It is based on the following assumptions:

X2.5.2.1.1 A constant dissolved chemical concentration in ground water.

X2.5.2.1.2 Equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table.

X2.5.2.1.3 Steady-state vapor- and liquid-phase diffusion through the capillary fringe, vadose zone, and foundation cracks.

X2.5.2.1.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.5.2.1.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the enclosed space, where the convective transport into the building through foundation cracks or openings is negligible in comparison with diffusive transport.

X2.5.3 Should the calculated  $RBSL_{air}$  exceed the pure component solubility for any individual component, ">S" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X2.6 *Surficial Soils—Ingestion, Dermal Contact, and Vapor and Particulate Inhalation.*

X2.6.1 In this case it is assumed that chemical intake results from a combination of intake routes, including: ingestion, dermal absorption, and inhalation of both particulates and vapors emanating from surficial soil.

X2.6.2 Equations used to estimate intake resulting from

ingestion of chemicals are given in Table 1. For dermal contact with chemicals in soil, the intake rate and the surficial soil chemical concentrations and intake rate are assumed constant over the exposure duration.

X2.6.3 Equations used to estimate intake resulting from dermal absorption of chemicals are given in Ref. (1) for dermal contact with chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and absorption rates remain constant over the exposure duration.

X2.6.4 Equations used to estimate intake resulting from the inhalation of particulates follow guidance given in Ref. (1) for inhalation of airborne chemicals. For this route, it has been assumed that surficial soil chemical concentrations, intake rates, and atmospheric particulate concentrations, remain constant over the exposure duration.

X2.6.5 Equations used to estimate intake resulting from the inhalation of airborne chemicals resulting from the volatilization of chemicals from surficial soils follow guidance given in Ref. (1) for inhalation of airborne chemicals.

X2.6.6 A conceptual model for the volatilization of chemicals from ground water to outdoor air is depicted in Fig. X2.3. For simplicity, the relationship between outdoor air and surficial soil concentrations is represented in Tables X2.2 and X2.3 by the "volatilization factor"  $V/F_{air}$ ,  $[(\text{mg}/\text{m}^3\text{-air})/(\text{mg}/\text{kg-soil})]$  defined in Table X2.1. It is based on the following assumptions:

X2.6.6.1 Uniformly distributed chemical throughout the depth  $0-d$  (cm) below ground surface.

X2.6.6.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X2.6.6.3 Diffusion through the vadose zone.

X2.6.6.4 No loss of chemical as it diffuses towards ground surface (that is, no biodegradation), and

X2.6.6.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X2.6.7 In the event that the time-averaged flux exceeds that which would occur if all chemical initially present in the surficial soil zone volatilized during the exposure period, then the volatilization factor is determined from a mass balance assuming that all chemical initially present in the surficial soil zone volatilizes during the exposure period.

X2.7 *Subsurface Soils—Inhalation of Outdoor Vapors*

X2.7.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from hydrocarbons contained in subsurface soils located some distance below ground surface. Here the goal is to determine the  $RBSL_{air}$  for

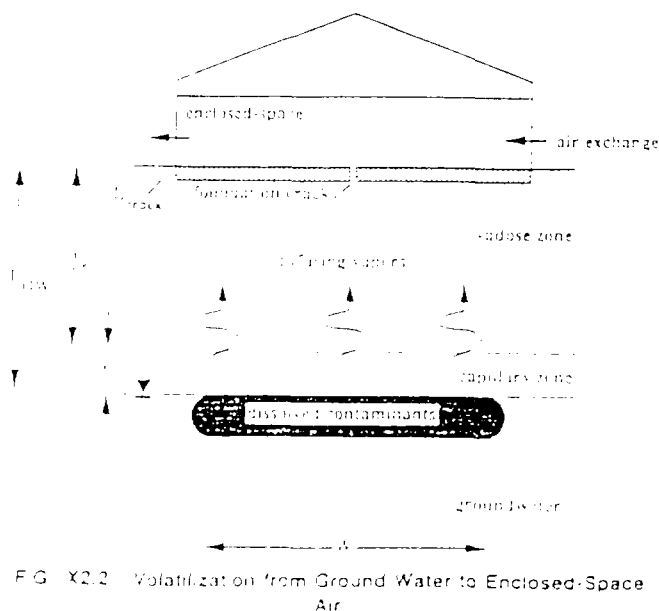


FIG. X2.2 Volatilization from Ground Water to Enclosed-Space Air

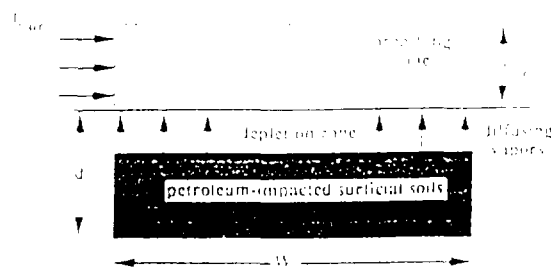


FIG. X2.3 Volatilization from Surficial Soils